MONITORING OF MOVABLE STEEL TRUSS BRIDGES

Hans De Backer, Philippe Van Bogaert, Amelie Outtier, Ken Schotte, Wim Nagy

Ghent University, Department of Civil Engineering, Ghent, Belgium
Hans.DeBacker@UGent.be, Philippe.VanBogaert@UGent.be, Amelie.Outtier@UGent.be,
Ken.Schotte@UGent.be, Wim.Nagy@UGent.be

INTRODUCTION

Monitoring of structural parameters during construction can be an important aid during execution. Especially when studying the long-term behaviour of structures, e.g. build-up of ground pressures or fatigue effects, it can become necessary to resort to monitoring. This research paper discusses two such projects.
A first project is concerned with the refurbishment of part of the counterweight structure of one of the bascule bridges crossing the "Van Cauwelaert"-locks, which is one of the most important lock allowing entrance the Port of Antwerp, Belgium. Because of uncertainty about the size of the stress cycles in the movable part during bridge operation, a number of strain gauges are installed during renovation before any of the axles connecting the bridge to the bascule system are installed. Afterwards, stress build up will be monitored during the remaining construction phases, as well as during test operation of the bridge to verify design assumptions. Monitoring will continue afterwards during the first few months of operation.
A second project deals with a similar bridge, also in Antwerp. A number of connections in this bridge have recently been determined as fatigue sensitive, so refurbishment is planned to strengthen the bridge at key locations. Measurements will take place before during and after the refurbishments in order to validate the strengthening operations.
This article gives an overview of these experiences and on the lessons learned concerning power supply, possible electromagnetic interference, working on bridges in use and structural consequences.

1 BACKGROUND

In Belgium, a large number of bridges and fly-overs were built in recent years; all of them part of the European High Speed Train network. A considerable percentage of the large and medium span bridges amongst them were subjected to test loading [1, 2] using heavy construction lorries or test trains before completion, during which strains and or accelerations were measured for comparison with the basic design premises. These measurement projects have serve as an introduction into the monitoring field and have allowed for building extensive and varied know-how concerning in situ measurements [3, 4].
For the study of the long-term behaviour of civil infrastructure, it often becomes necessary to resort to long-term monitoring of certain structural parameters, such as the strains, temperatures, accelerations, frequencies, etc. Especially when the nature of the structures necessitates the use of an independent power source for the measurement system and prohibits the use of wired connections with the environment, a fully autonomous measurement system becomes necessary. This research paper discusses two such applications in the fields of bridges and port infrastructure and the possible pitfalls in developing such a monitoring system.

2 “KRUISSCHANS” BRIDGE IN THE PORT OF ANTWERP

2.1 Introduction

The “Kruisschans” Bridge, shown in *Fig. 1*, is one of the movable bridges bracketing the “Van Cauwelaert” lock, which is one of the main entrances to the inner harbour of the Port of Antwerp, protected from tidal effects. The renovation of the “Van Cauwelaert” lock together with the modernisation of the close by “Royers” lock and the raising of the bridges over the nearby Albert canal forms part of the waterways project aimed at making the canal and river transportation an attractive alternative for road transport. Raising the bridges over the Albert Canal will enable barges to travel the inner harbour and the Albert canal, which travels to Liege and Germany, carrying containers stacked four high. This forms part of the on-going effort to achieve a modal shift away from road transportation and thus better mobility.

The modernisation of the “Van Cauwelaert” lock is also significant for the Port of Antwerp, as the renovated lock doors will make it possible to handle the growing number of barges travelling on rivers and canals quickly and more efficiently. Furthermore, extreme weather conditions such as high winds and heavy rain will no longer interfere with operation of the lock, ensuring that it can remain in operation permanently.

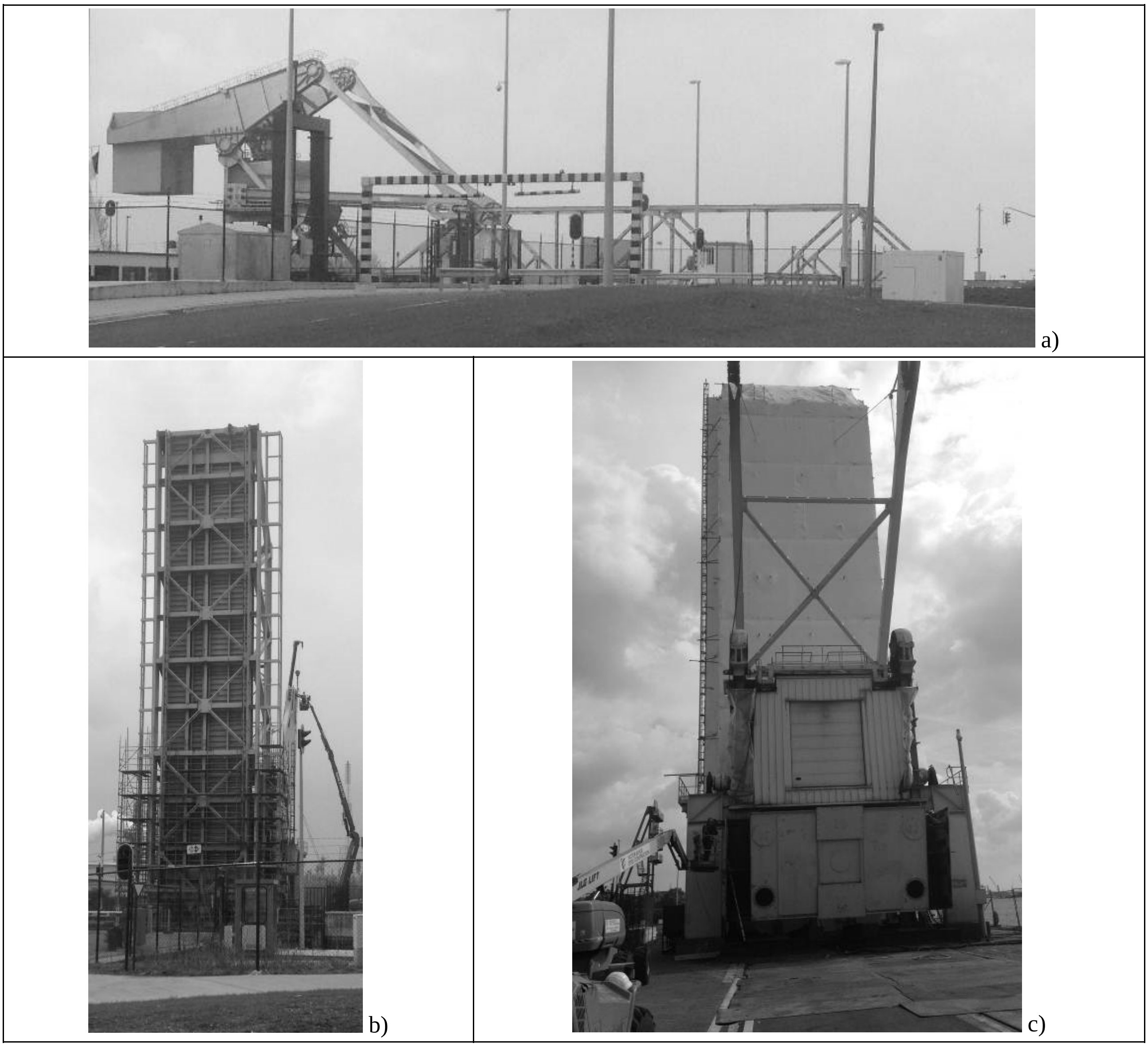

Fig. 1. “Kruisschans” Bridge in the Port of Antwerp: in operation (a and b) and during renovation (c)

The movable “Kruisschans” Bridge is situated at the right bank of the river Scheldt. In 1992, this bridge replaced the original movable bridge from 1928, during a previous renovation project of the locks. This bascule bridge is of the Strauss trunnion type. This type of bascule bridge is preferred over other types of movable bridges because it offers the fastest operation, and a greater level of safety. It can open a channel for large ships upon approach, without danger of collision. Bascule bridges also have the ability to allow smaller vessels to pass by opening only partially when necessary.

2.2 Experimental setup

One of the determining factors in the redesign of a trunnion type bascule bridge is the low-cycle fatigue due to the movements of the bridge. In order to verify all design assumptions, it was decided by the client to install 36 strain gauges, mainly on the balance beams, but also on the hoist beams and gear rods. In addition, it was decided to install most strain gauges at the steel construction plant where all the parts are strengthened and repainted in an unloaded condition. This allows for monitoring the stress cycles during normal bridge operation and in theory also for registering the stress build-up during assembly of the bridge. This last factor would allow for determining the absolute stress values.

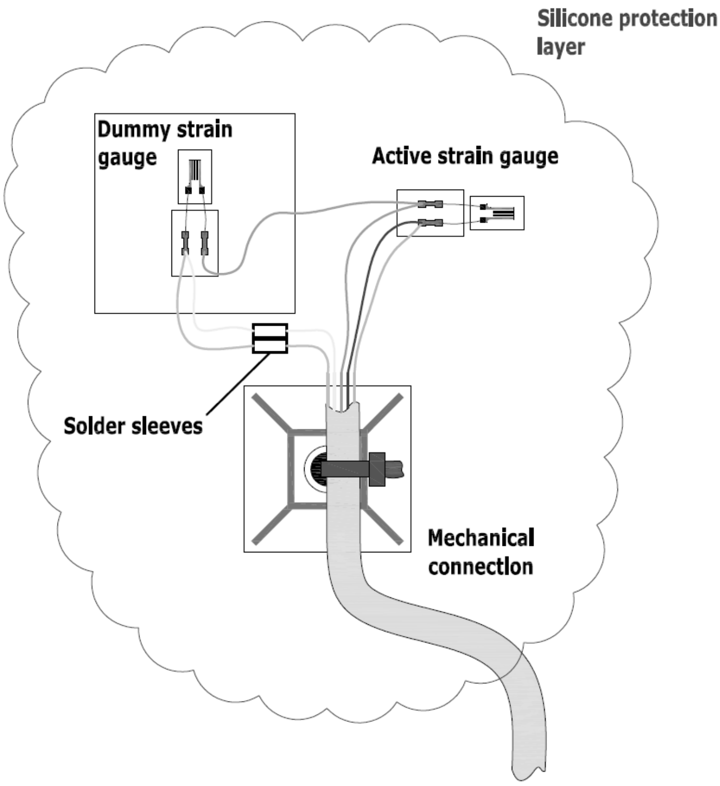

Fig. 2. “Kruisschans” Bridge in the Port of Antwerp: half bridge strain gauge configuration

Since the actual measurements would be several months after installation and zeroing of the strain gauges, a half bridge installation scheme was chosen, as shown in *Fig. 2*. However, the stress field in the balance beams is not strictly unidirectional, making it more difficult to determine the overall stresses in a certain cross-section, based on a single strain gauge. This necessitates a more complicated strain gauge application method.

The dummy strain gauge, which is responsible for filtering out all of the temperature and electromagnetic noise influences on the recorded measurement signal of the active strain gauge, cannot simply be glued to the balance beam surface in a perpendicular direction to the active strain gauge, since transverse stresses would influence the measured stress values because of the Poisson-effect. The dummy strain gauges are thus installed on a separate 3 cm by 3 cm steel plate, which can entirely be prefabricated in the controlled conditions of the laboratory. Afterwards, this steel plate is attached to the steel of the balance beam using a heat transmitting tape, ensuring that a thermal connection exists between the balance beam and the dummy plate, but allowing no transfer of mechanical stresses to the steel of the dummy plate. The connection is thus only relevant for thermal and electromagnetic effects but not for the structural behaviour of the structure

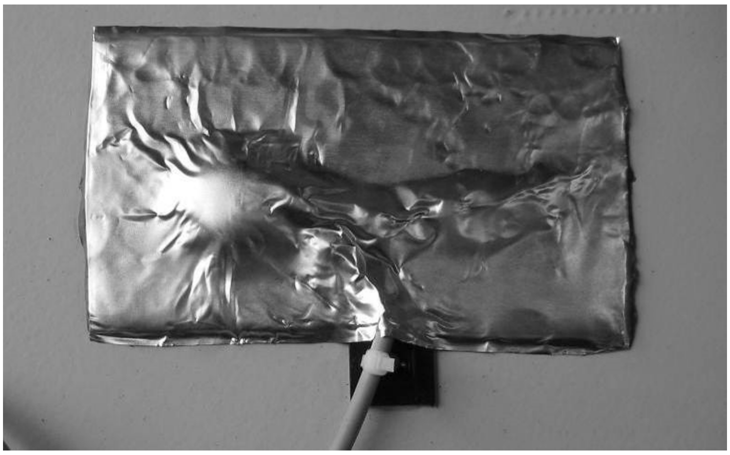

Fig. 3. “Kruisschans” Bridge in the Port of Antwerp: strain gauge protection layer

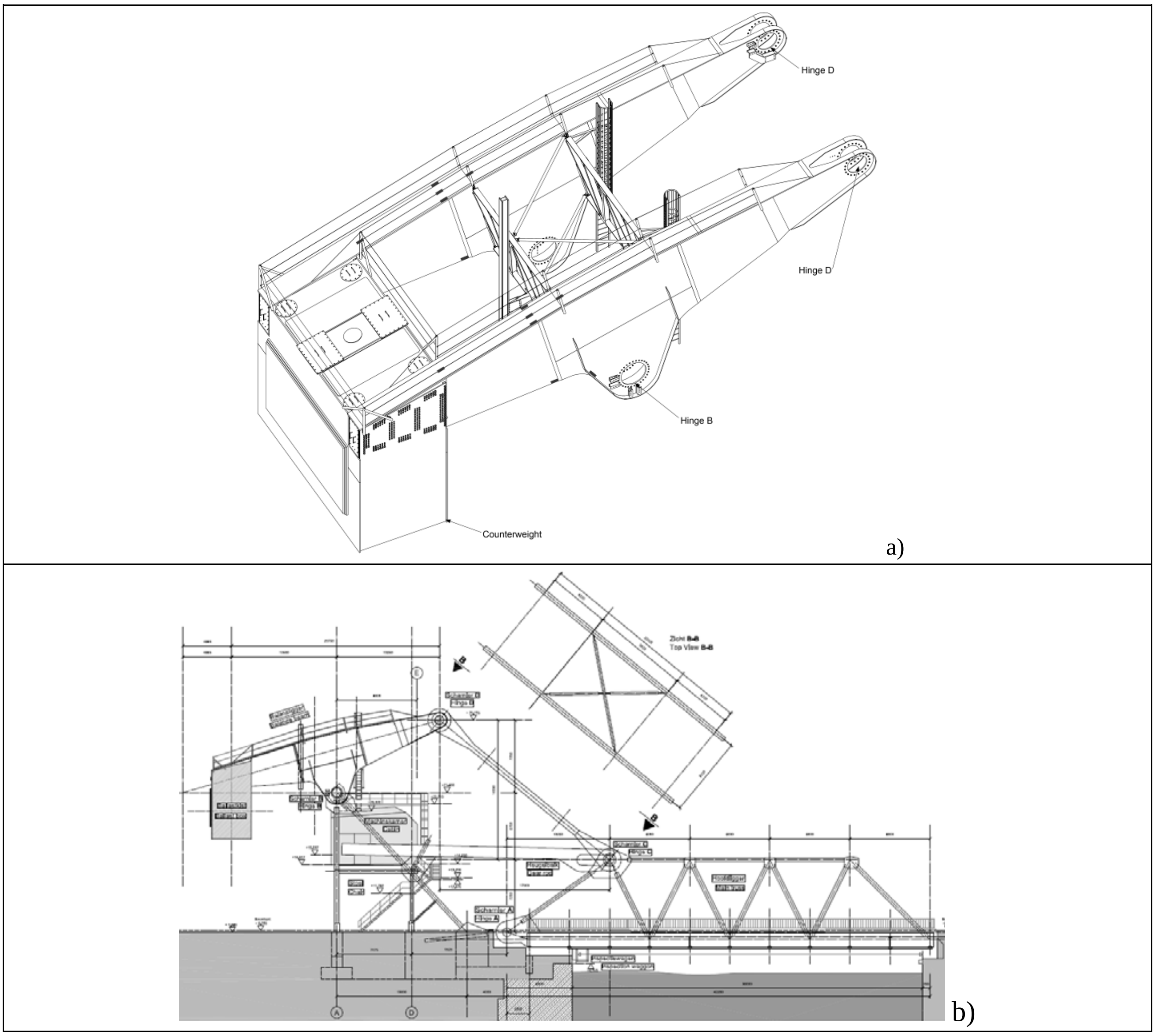

Fig. 4. “Kruisschans” Bridge in the Port of Antwerp: strain gauge protection layer

Since the strain gauges will not be removed after the end of the measurement period, the entire setup has to be permanently protected against weather conditions. The protection has to ensure that the untreated steel upon which the strain gauges have to be glued, in order to end up with relevant results, cannot lead to corrosion problems. Because of this, the entire strain gauge setup is protected using a synthetic viscous kneadable putty, creating a sealed-off environment around the strain gauge setup, but inducing no mechanical resistance in the strain gauge. The surface of this putty is finished with a thin aluminium layer, as can be seen in *Fig. 3,* which allows for repainting of the entire area using the same paint procedure as used for the entire “Kruisschans” Bridge. This results in the monitoring system being quite invisible, the measurement cables notwithstanding, although they will be guided to the corners and behind the stiffeners of the balance beam where possible. The location of most of the strain gauges is shown in *Fig. 4*.
To allow for easy interpretation of the stress and strain results, the angle of the movable part of the bridge will also be recorded in the machine chamber and registered using the same data-acquisition system with identical measurement frequency. This allows for interpretation of the stresses for each step in the bridge operation.

2.3 Results

Some results concerning the movement of the bridge and the maximal strains which were measured are summarized in *Fig. 5*. Each diagram represents the variation of a number of sensors during one operation of the entire bridge, i.e. opening and closing of the bridge. The quality and stability of the measurements is quite clear. The maximal value, being 740 μS, clearly illustrates the importance of design verifications using measurements, since it corresponds with a stress variation of 155 MPa, which is quite considerable.

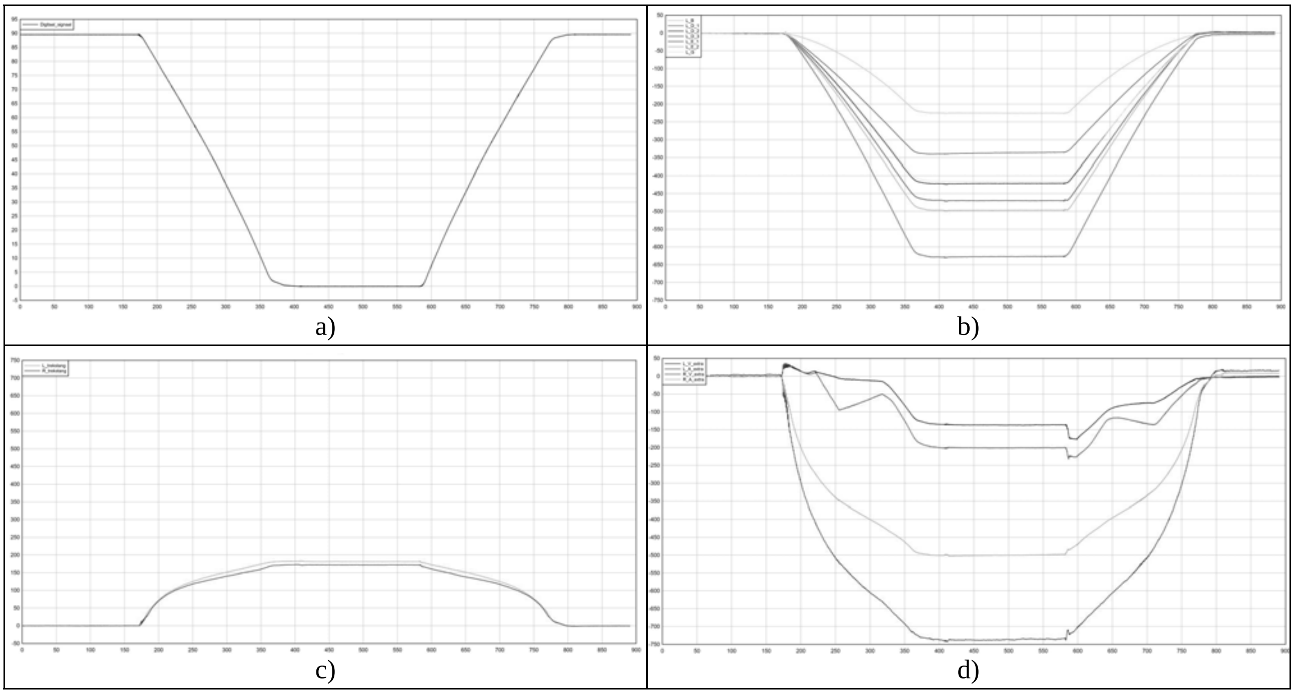

Fig. 5. a) Registration of the position of the movable part of the bridge (between 0° and 90°);
b) Variation of the strains in the balance beam (between 0 and -630 μS);
c) Variation of the strains in the traction beam (between 0 and 180 μS)
d) Variation of the strains in the support structure (between 0 and -740 μS)

3 MOVABLE BRIDGE 2

3.1 Introductions

A second project deals with a similar bridge, also in Antwerp. Locations of strain gauges are based on the areas suffering the heaviest wear up to this point. An example is given in *Fig. 6*.

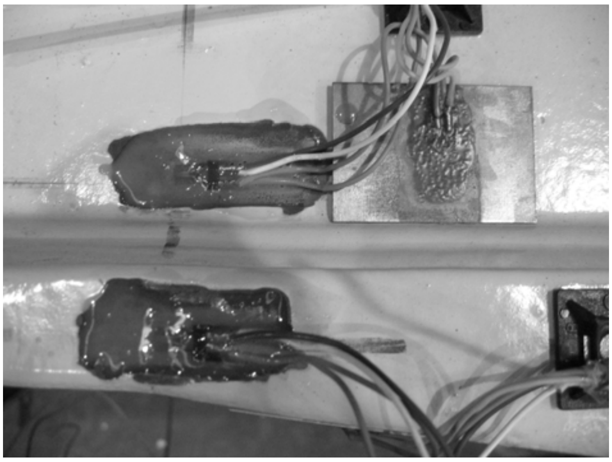

Fig. 6. Strain gauges positioned at the weld toe

3.2 Measurements

A number of connections in this bridge have recently been determined as fatigue sensitive, so refurbishment is planned to strengthen the bridge at key locations. Measurements will take place before during and after the refurbishments in order to validate the strengthening operations. The actual measurements will take place between September 2013 and September 2014.

4 SUMMARY

When studying the long-term behaviour of structures, it often becomes necessary to resort to monitoring of certain structural parameters. This research paper discusses two such monitoring projects which are used to verify design assumptions.
As an example, deals with verifying the stress cycles for fatigue verification in a movable bridge. This can lead to an adequate estimation of the remaining fatigue life after renovation. In addition, the measurement results can be used to verify the unbalance of the bascule system.
This article gives an overview of these experiences and on the lessons learned concerning power supply and possible electromagnetic interference in harsh construction site conditions. Furthermore, the most important results are discussed in short.

REFERENCES

[1] De Backer H, Outtier A, Van Bogaert P, "High precision strain gauge measurements in areas of high stress concentrations of orthotropic plated bridge decks" Insight, Vol. 49, No. 7, pp 384-389, 2007.

[2] De Backer H, De Pauw B, De Corte W and Van Bogaert P, "Precast HPC post-tensioned alternatives for a railway crossing viaduct", *Proc. of the 3rd Int. Symposium on HPC*, CD-ROM, 2003.

[3] De Backer H, De Corte W and Van Bogaert P, "A case study on strain gauge measurements on large post-tensioned concrete beams of a railway support structure" Insight, Vol. 45, No. 12, pp 822-825, 2003.

[4] De Pauw B, De Backer H, De Corte W. and Van Bogaert P, "Two Alternatives for a Railway Viaduct in Densily Populated Area", *Proc. Conference Int. Ass. For Bridge and Struct. Eng. IABSE. Role of Structural Engineers towards Reduction of Poverty*, pp 455-462, 2005.